ATOLL RESEARCH BULLETIN

NO. 571

MICROATOLL EDGE TO ENSO ANNULUS GROWTH SUGGESTS SEA LEVEL CHANGE

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ISSUED BY
NATIONAL MUSEUM OF NATURAL HISTORY
SMITHSONIAN INSTITUTION
WASHINGTON, D.C., U.S.A.
JULY 2009

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ABSTRACT

Using microatolls (MAs) located in a patch on the reef flat of an atoll in the central Pacific, we assessed the vertical changes in height of surface annuli in order to learn something about sea-level changes in this location. Our approach was three pronged. First, using the full radii of 13 MA heads, we calculated a sea-level rise of 0.1 mm/yr over an average growth period of 19 years ending on August 7, 2005. Second, using the space between the 1997 ENSO (El Niño Southern Oscillation) annulus and the outer edge as of August, 2005, we calculated a sea-level rise of 0.2 mm/yr in 14 MA heads. Third, we returned to the site for a brief visit in 2008 and using the 97ENSO annulus to living edge area of 57 MAs concluded that over the 10 years sea level in the area had risen at a mean rate of 1.6 mm/yr. All together, our data suggest that during our times of observation (1998 - 2008) sea-levels on the ocean flat of Abaiang Atoll in the Republic of Kiribati have risen at an average rate ranging from 0.1 to 0.2 mm/yr.

INTRODUCTION

In the shallow waters of open ocean reef flats in the equatorial Pacific, the stony coral, *Porites lutea*, often forms microatolls. These disk-shaped colonies (Fig. 1) possess distinct surface annuli which are limited in their upward growth by the lower tides. In 1998, with X-ray photographs of a microatoll section, we determined that the surface annuli on *Porites lutea* microatolls reflected the coral's yearly growth (Flora and Ely, 2003). We also noted that the height of the annulus formed during the 97 ENSO event reflected the rise in water level accompanying the shift in prevailing winds (from the usual north easterlies to strong westerlies) and the flow of near equatorial waters changing from west to east. Because we were teaching in the nearby Tabwiroa Secondary School during that period, it was possible for us to keep a close eye on the living edge and actually observe the ENSO annulus being formed. We also noted that the upper surface of the annual rings fluctuated in height in association with changes in LMSL (lower mean sea levels) as recorded by the Australian National Tidal Centre. We were

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Manuscript received 10 February 2009; revised 3 June 2009

Figure 1. June 2008: Charles J. (Jerry) Flora is standing on one of the microatolls in the Abaiang MA Garden. His right foot is on the 97 ENSO annulus. This garden has between 600 and 700 recognizable and useful heads of *Porites lutea*.

also aware that the upper surface of microatoll annuli have been used to infer historical changes in relative sea levels due to subsidence and uplift (Zachariasen et al 2000, Natawidjaja et al 2004) and knew that against the backdrop of debate about sea level rise due to global warming, several authors have also looked at the surface topography of microatolls as an indicator of sea level trends in the present. (Woodroffe and McLean 1990, Spencer et al 1997; Smithers and Woodroffe 2001). In these studies, X-radiography of the coral skeleton was used to correlate surface topography with internal growth bands. However, the use of X-radiography requires the collection and destruction of the MAs studied and a consequent end to the growth recorded in those specimens. In the work reported here, we used only the surface topography of *P. lutea* microatolls in situ as a ready made, non-destructive means of tracking on-going changes in LMSL. We were aware that in at least two previous papers (Scoffin and Stoddart, 1978; T. Spencer et al, 1997) the heads evaluated had been damaged and that regrowth had concealed evidence of sea-level fluctuations. This was not the case with those we used on the Abaiang, Tabwiroa flat. These heads were complete, healthy and undamaged as shown in Figure 1.

Our **first** approach in using the MAs in the Abaiang Microatoll Garden for sea-level assessments was conducted in August, 2005. Altogether we used data from 13 heads and in each we measured the heights of annuli in four radii, two on the diameter parallel to the reef crest and two perpendicular as shown in Figure 2. Our **second** approach also conducted in August 2005, used the area between the 97 ENSO annulus

and the outer, (living) edge (Fig. 3). This also involved 4 lines, two at the ends of each of the two diameters just described. The **third** approach was accomplished in June, 2008 and as shown in Figure 4, used only two annuli in the 97 ENSO to outer edge area. All our work was conducted on the reef flat off Tabwiroa, Abaiang (Fig. 5) in the Republic Of Kiribati (Fig. 6 and Fig. 7).

MATERIALS AND METHODS

All our work as reported here was conducted in the Republic of Kiribati (Fig. 5 and Fig. 6) on Abaiang atoll just north of Tarawa, the capital of Kiribati. A sketch map of Abaiang is shown in Figure 7 and the location of the large microatoll garden where we collected our data is on the ocean flat off the village of Tabwiroa.

The First Approach

After being cleaned of sediments and fleshy algal overgrowth, a profile of the heights of the upper surface of each of fourteen microatolls was measured along two separate transect lines across the full microatoll diameter and passing through its estimated center. One transect was laid down parallel to the reef crest and shore line, and the other was laid down perpendicular to it, (Fig 2). For purposes of evaluating change over time, these full width transects were then bisected to render four radial transects for each microatoll, running from center (oldest) to perimeter (youngest). Vertical heights of annuli were measured in relation to an artificial horizon established immediately above the microatoll surface by means of an aluminum angle bar leveled and suspended across the full diameter of each microatoll (Fig. 2). Measuring the full diameter and then dividing it into two assured that any error in leveling the bar would be cancelled when the radial transects were averaged against each other. For this reason, the length of our measuring device (91 cm) limited the size of the microatolls we were able to include in the study. Distances from this artificial horizon down to the microatoll surface were measured all along the transect using a mechanical depth gauge. A linear regression was calculated for each of these transect data sets. This slope was then used to infer the rate of vertical change of LMSL during the life of the coral along each transect. (We recognize that the older parts of the MA surface are more susceptible to wear and tear but in the area of our work, the annuli showed little such effect - see Figures 1 and 2 as examples.) The rate of vertical change was calculated as follows: the difference between the innermost (nearest the center) and outermost (closest to the outer edge) values of Y on each linear regression line was divided by the estimated age in years of coral growth between those values. The age was estimated by dividing the horizontal distance between these Y values by a lateral growth rate of 2.0 cm per year. (The growth rate we reported from our 1998 data was 2.2 cm\yr (Flora and Ely, 2003 but from later work, we settled on 2.0), (Flora et al, 2007). We used this same figure to position the depth gauge, i.e., heights were measured every 2.0 cm.

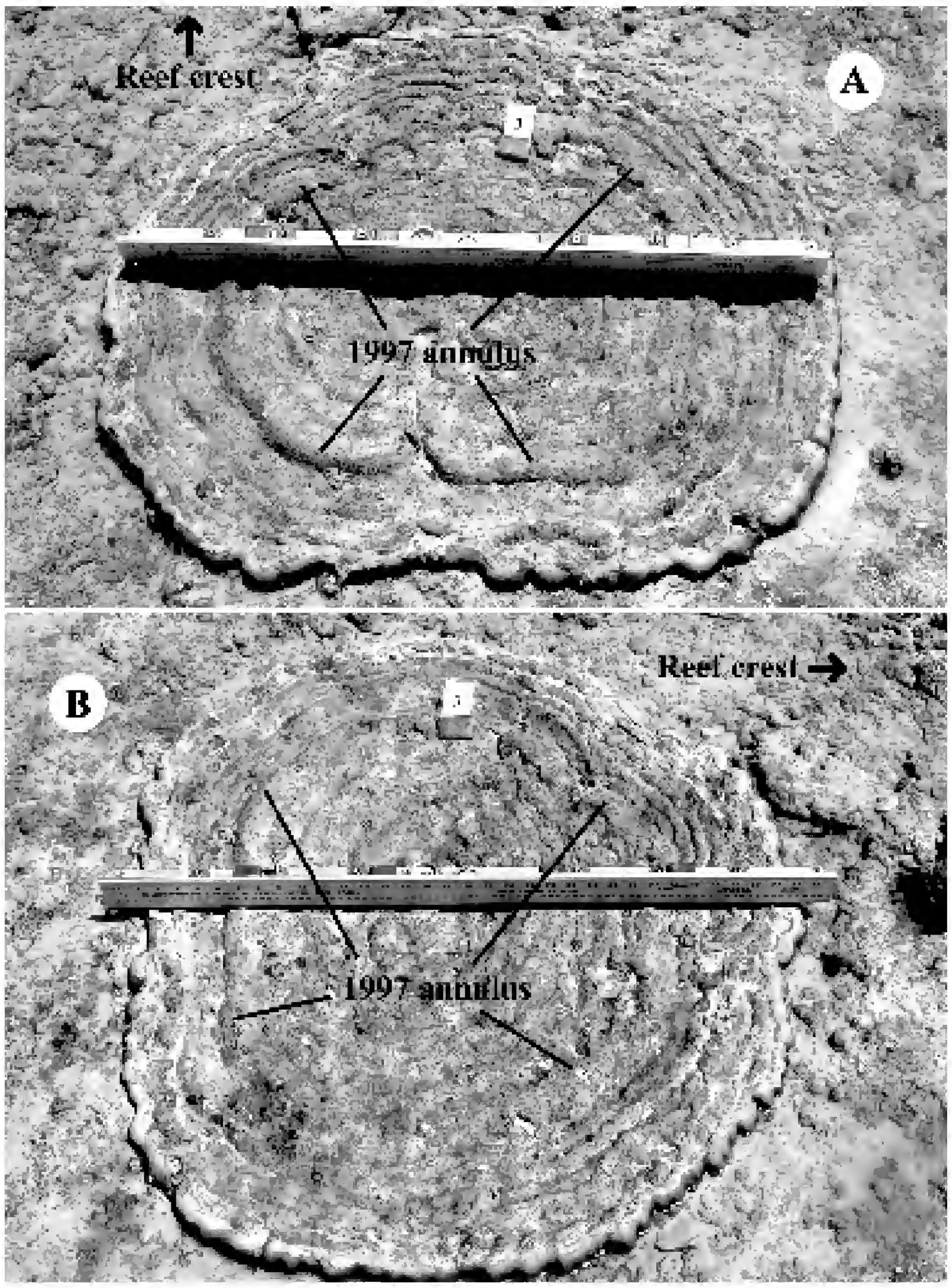

Figure 2. First approach: The transect in A is parallel to the reef crest. That in B is perpendicular to it.

The Second Approach

The same approach was used here except that each transect was shortened to include only those height measurements from the 1997 ENSO annulus out to that of 2004 (the outermost annulus to be measured for height, Figure 3). Regressions and rate of vertical change were then recalculated for these data subsets.

The Third Approach

In this study, we used the ten year interval between the 1997 ENSO event and that of our visit in June, 2008. Because we were present during the time the ENSO annulus (Fig. 2) was being formed, we have an accurate date of its formation.

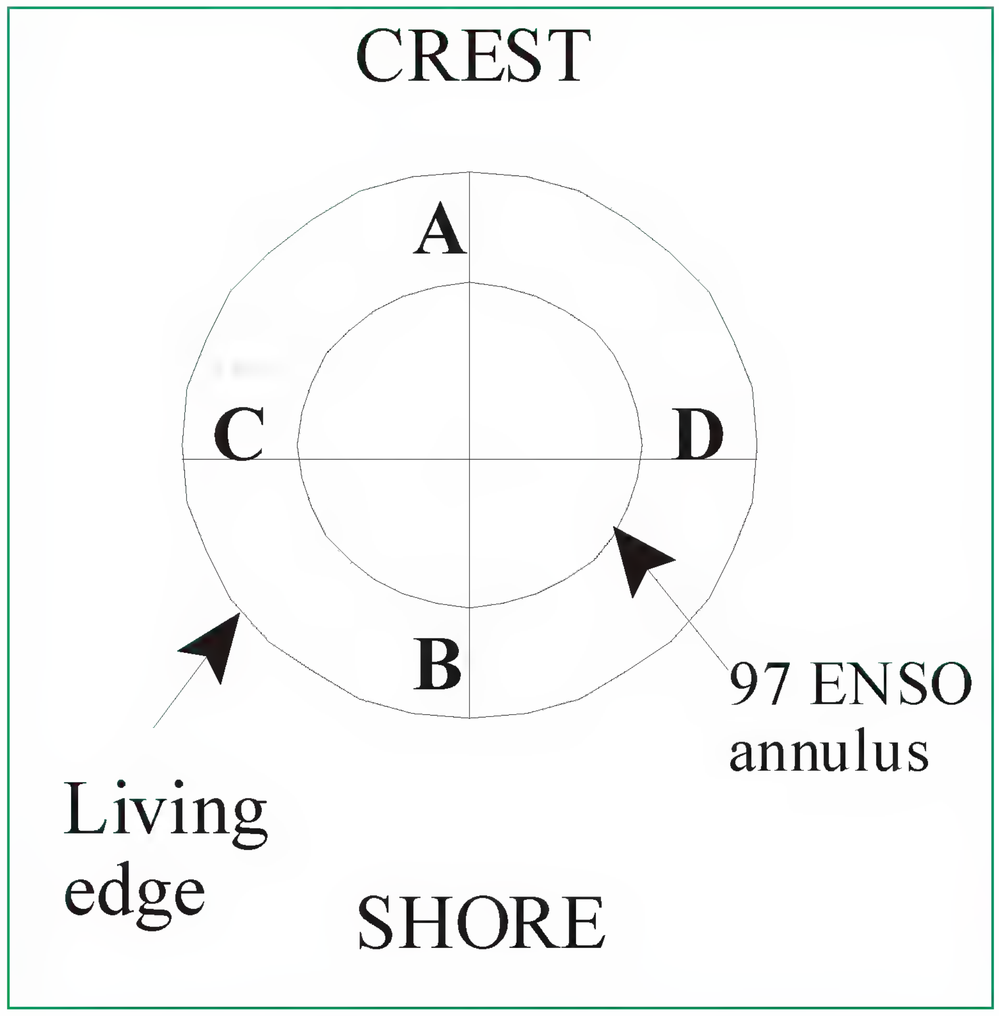

Figure 3. Second approach: This shows the area used in gathering data for the second approach.

After the space between the 97 ENSO annulus and the living edge had been scrubbed to show the growth rings, we determined the vertical distance from an artificial horizon above the annulus closest to the lump and that nearest the outer, living edge as shown in Figure 4. A straight metal bar was carefully positioned above the area to be evaluated and the ends were adjusted by adding or removing bits of debris until the spirit level bubble was centered. Then the distance from the lower edge of the bar directly down to the top of the designated annulus was recorded in centimeters (cm).

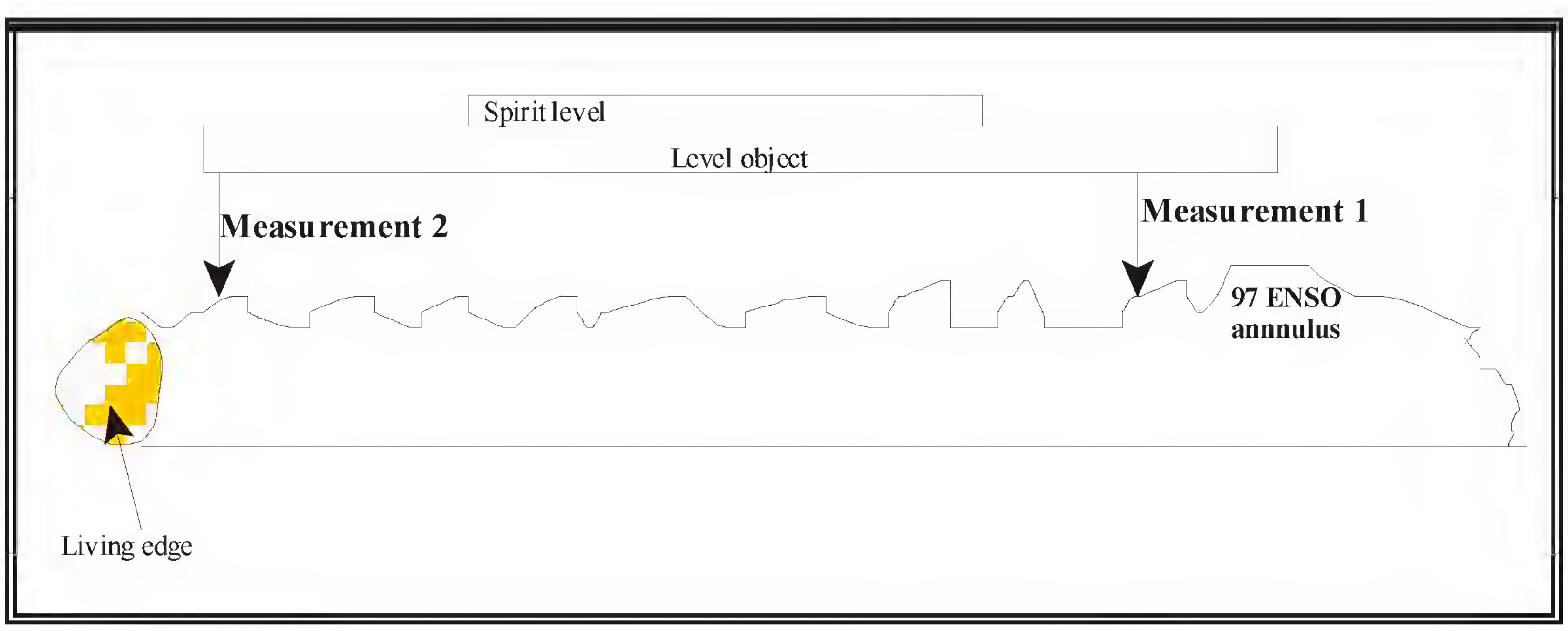

Figure 4. Third approach: In the area between the 97 ENSO annulus and the outer (living) edge, only two measurements were made for each of the 57 MAs and in all cases they were the two in the line closest to shore as shown in B of Figure 3.

Regrettably because we were self funded, we had too little time to gather more data on this matter. We examined a total of 57 MAs distributed between the crestward and shoreward edges of the garden in which there were several hundred heads (Fig. 1). Only one pair of measurements was made for each MA head and because we suspected that environmental conditions differed slightly from one part of the head to another and for consistency, all measurements were made on the line closest to the shore. Differences in height are given in Table 1.

Table 1. Changes in height (cm) between annulus 1 and annulus 2 (see Figure 4) for 57 Microatolls over 10 years.(+ means the outer annulus was taller than the inner one, 0 means no change and - means it was shorter).

MA	Change	*MA*	Change	*MA*	Change	*MA*	Change	*MA*	Change	*MA*	Change
1	**+1.7**	*11*	**-1.8**	*21*	**+0.4**	*31*	**-0.3**	*41*	**+0.7**	*51*	**0**
2	**+0.3**	*12*	**-0.5**	*22*	**+0.3**	*32*	**-0.8**	*42*	**0**	*52*	**+1.0**
3	**+1.3**	*13*	**-1.3**	*23*	**+0.3**	*33*	**-0.3**	*43*	**+0.6**	*53*	**+2.0**
4	**+1.3**	*14*	**-1.5**	*24*	**+0.2**	*34*	**-0.4**	*44*	**+0.6**	*54*	**0**
5	**+0.5**	*15*	**+0.7**	*25*	**-0.3**	*35*	**+0.7**	*45*	**+1.1**	*55*	**+0.9**
6	**+1.8**	*16*	**-3.5**	*26*	**+0.1**	*36*	**-0.1**	*46*	**+0.5**	*56*	**+1.1**
7	**+0.8**	*17*	**-0.3**	*27*	**-0.3**	*37*	**+0.3**	*47*	**-0.5**	*57*	**+0.6**
8	**+2.0**	*18*	**-0.3**	*28*	**-0.3**	*38*	**-0.1**	*48*	**+0.3**		
9	**-1.5**	*19*	**-0.5**	*29*	**+0.4**	*39*	**+0.1**	*49*	**+1.0**		
10	**+0.6**	*20*	**0**	*30*	**0**	*40*	**+0.1**	*50*	**-0.6**		

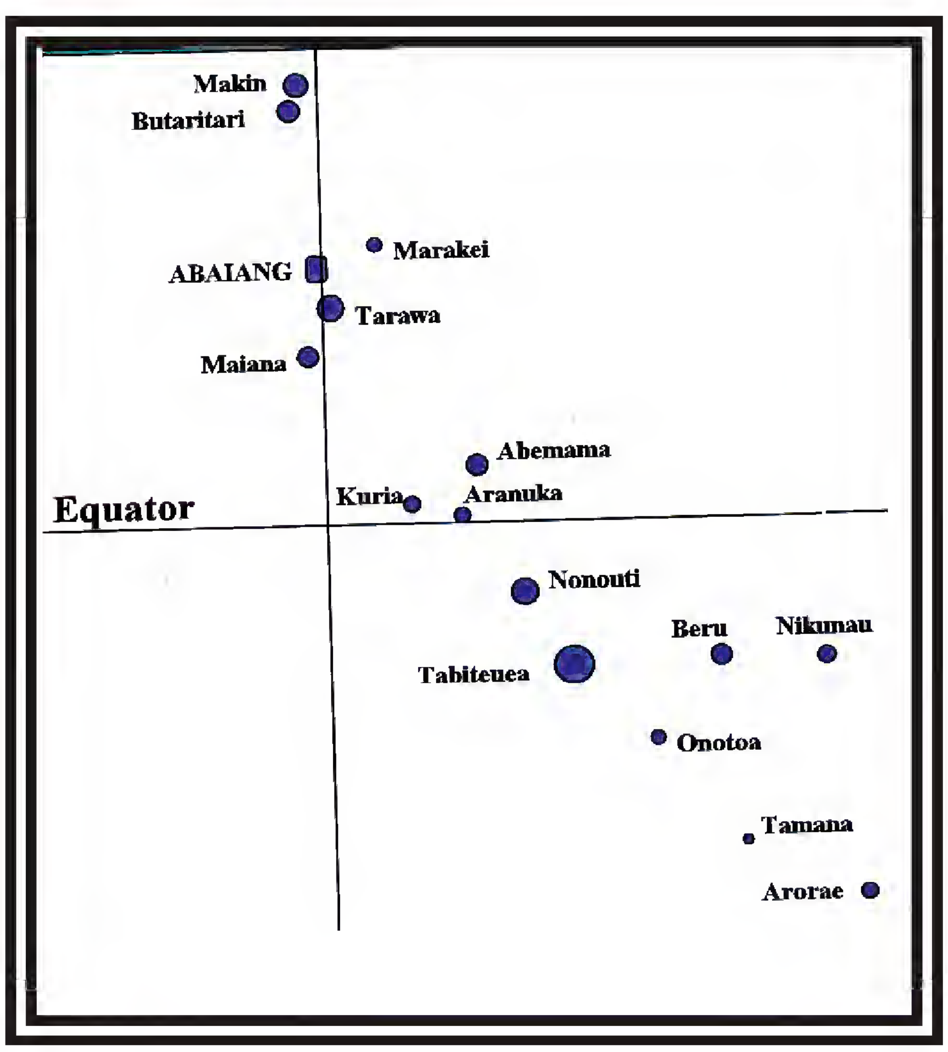

Figure 5. The western islands of Kiribati.

Figure 6. Satellite photo of Tarawa (lower) and Abaiang (upper). The area between the two atolls is not land, it is heavy wave action.

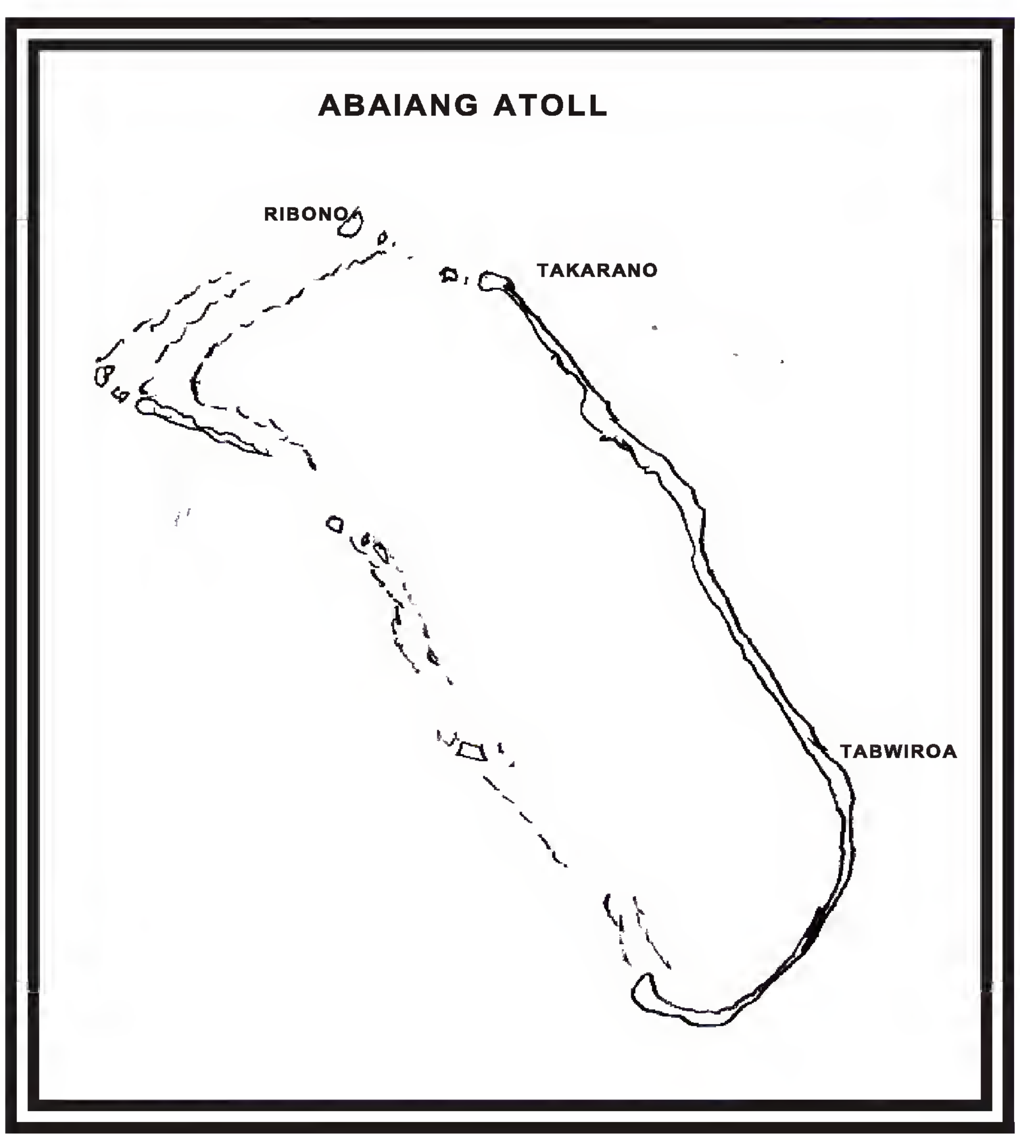

Figure 7. Sketch map of Abaiang showing only a few of its several villages. Our working site is under the letter T of Tabwiroa.

RESULTS

The First Approach

We found that of 36 radial transects, 67% had positive slopes, 33% were negative. The range was -0.046 to +0.042 with a mean slope of +0.0054 (Fig. 8). The mean rate of the rise in LMSL was calculated at 0.1 × 0.4 mm/yr.

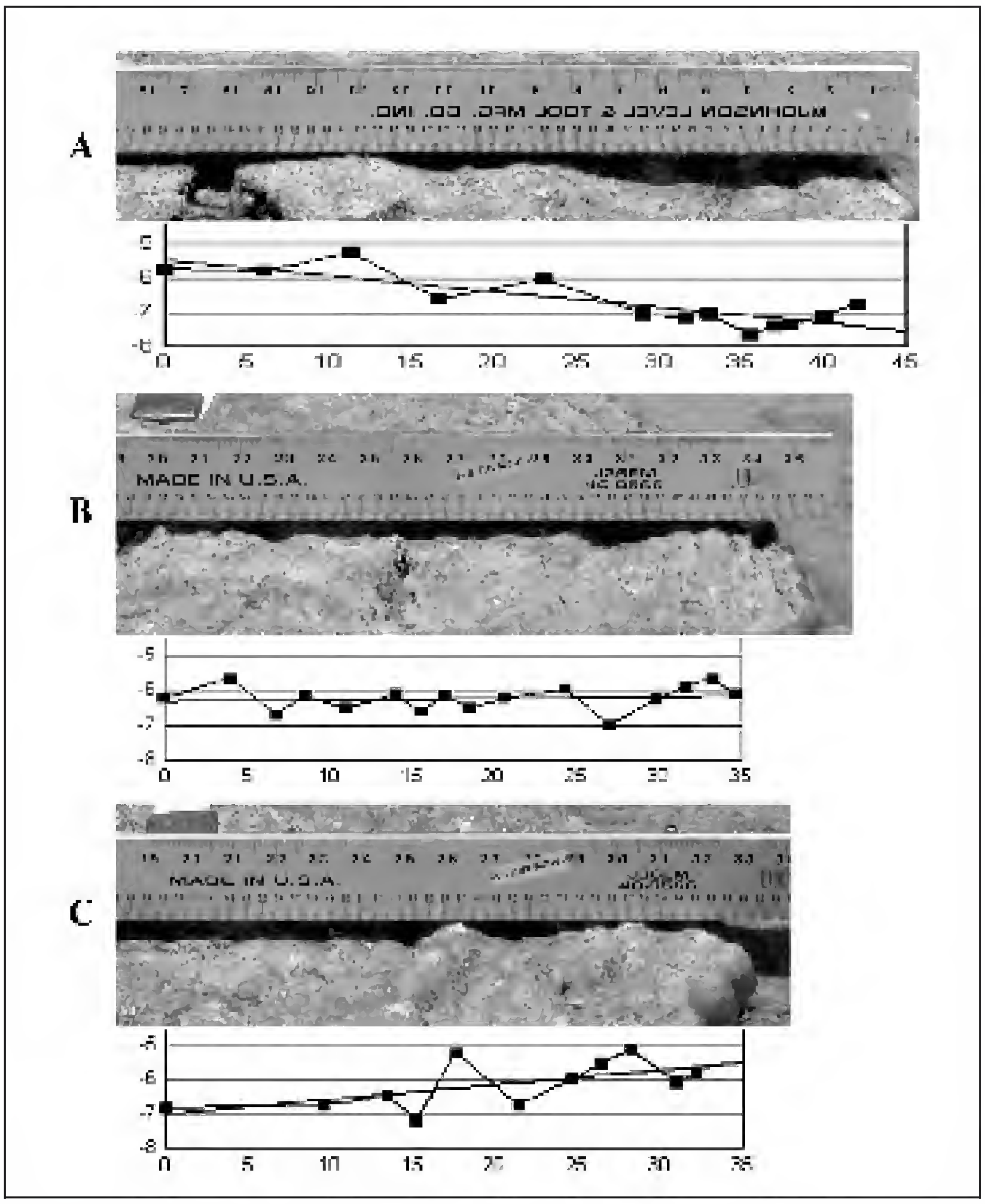

Figure 8. These three radial transects illustrate the range from most negative slope (A) to the most positive slope (C). The middle transect (B) is closest in value to the mean slope. All axis numbers are in cm.

The Second Approach

We found that 58% of 36 radial transects had positive slopes and 42% were negative. The range was from -0.078 to +0.084 with a mean slope of +0.010. The mean rate of height increase as a result of LMSL rising calculated from 1997 to 2004 was 0.2 × 0.8 mm/yr.

The Third Approach

Of the 57 microatolls measured in 2008, 32 showed a positive slope over the 10 year period, 5 showed no difference in height, 20 showed a negative slope, i.e. 32 suggested that LMSL had risen, 5 that there had been no change and 20 that it had declined. We recognize that many environmental factors (e.g. mechanical damage by people or storms, differences in adjacent biota, differences in water quality, sedimentation, proximity of other MAs, etc.) can affect the growth of an annulus, either horizontally, vertically or both but because a majority showed an increase, we conclude that these data support the view that sea levels have risen over the 10 year interval.

The data (Table 1) show that the maximum rise in sea level was 7.31 mm in 10 years if only positive changes were recorded. But, if all data (+,0,- changes) were used, the increase was 0.2 mm/yr through the decade.

CONCLUSIONS

Assuming that geological events such as subsidence and or uplift have not occurred during this time interval, these data support the view that sea levels in this part of the central Pacific have risen between our first visit in 1997 and our most recent in 2008. This contention is also supported by comparing the Tarawa Tide Tables (prepared by the Kiribati Shipping Services Limited) of 1998 with those of 2005. We have calculated the levels of Mean Lower Low Water (MLLW) for the two years with results as follows:

In 1998, the MLLW was 0.2740 meters, i.e., 274.0 mm.
In 2005, the MLLW was 0.3732 meters, i.e. 373.2 mm.

Thus according to these two tide tables, the level of the lower low water rose 99.2 mm during the eight year interval. Given a steady increase, this would have been a rate of 12.4 mm/yr.

While the tide tables support the idea that sea levels have risen, the magnitude of the rate of change is very different than ours. The MA data suggest changes of .2 mm or less, these two tide tables suggest 12 mm or more per year. The difference could be explained by various considerations such as the tables being prepared for Tarawa not Abaiang, by people and methods we know nothing about. The Tarawa Tide Tables have been useful to our work on Abaiang but on several occasions, both time and levels have been quite different from our observations. These tables also differ greatly from the rates of increase proposed by using satellite altimetry, i.e. 2.8 × 0.4 mm/yr (Casenave and Nerem, 2004).

If our numbers are correct, insofar as microatolls play a role in reef growth, the central Pacific atoll nations are in little danger of drowning as their upward growth potential, which is equal to the lateral rate of 2.0 cm/yr, is probably far greater than most global warming experts have predicted. And even if the Tarawa Tide Table values shown above are correct, the MAs should be able to catch-up. Of course, if those who

forecast the demise of reefs throughout the oceans because of global warming related to, anthropogenic accumulations of CO_2 etc. are correct, the people of these atolls will be in trouble. However, our data do not suggest such catastrophic changes in sea level.

ACKNOWLEDGEMENTS

We thank Etosha Marie Pei Fun Moh, Mike Roman and Beretita Tawaia Roman for their five days of hard work on this project in 2008. We are grateful to Lawrence and Patti Offner who assisted us in 2005. We thank Taoata Muller and her husband Paul and their friend Tony and Beretita for assisting us in 2002. Without their efforts and the fact they worked without pay, other than our gratitude, this project would have been impossible.

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